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A RAND NOTE

THE INFLUENCE OF VISUAL-SPATIAL ABILITY AND STUDY PROCEDURES ON MAP LEARNING SKILL

Cathleen Stasz, Perry W. Thorndyke

June 1980

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Prepared For

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PREFACE

This study is the third in a series of Rand investigations of the process of map learning. The work reported here was performed between June 1978 and January 1979 and was supported by the Personnel and Training Research Programs of the Office of Naval Research. Additional results from this study will be documented in a subsequent report.

SUMMARY

This study investigated the influence of two sources of individual differences in knowledge acquisition from maps: abilities and learning procedures. Twenty-five subjects provided verbal protocols while attempting to learn two maps. Visual spatial ability was highly correlated with recall of spatial attributes of the map and with overall learning performance, while associative memory ability was most correlated with verbal attribute recall. Subject-selected procedures for encoding spatial information and assessing learning progress also distinguished the behavior of successful and less successful learners. However, subjects of high and low ability differed little in the study procedures they chose. Although both ability differences and procedure use were important contributors to performance, a direct comparison of these sources of variation suggested that abilities are most predictive of map learning. These observations led us to the following conclusions: (1) the use of effective study procedures can influence map learning performance, and (2) high ability subjects benefit more from the use of these procedures than low ability subjects.

ACKNOWLEDGMENTS

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CONTENTS

I. INTRODUCTION

Recent studies of individual differences in learning have postulated one of two sources of variation in individual performance: abilities or learning procedures. Abilities have generally been viewed as basic individual traits that are relatively enduring and resistant to change. Ability scores have historically predicted performance on a variety of school-related learning tasks and often interact with instructional style in those predictions (Cronbach & Snow, 1977). Recently, several cognitive psychologists have described abilities as fundamental, low-level processes for manipulating information, and they have attempted to identify the componential processes required to perform a variety of laboratory tasks (Hunt, Lunneborg & Lewis, 1975; Hunt, 1978; Snow, Marshalek & Lohman, 1976; Snow, 1977).

In contrast, other researchers have studied performance differences in terms of learning "procedures", or more complex combinations of low-level processes. Unlike abilities, these procedures are assumed to be discretionary, trainable, and improvable with practice. Considerable research has shown that such procedures may also predict performance on a variety of tasks (e.g., Fredriksen, 1969; Johnson, 1978; Paivio, 1971; Rohwer, 1973).

The relative diagnosticity of procedures and abilities for predicting learning performance is an important, yet unresolved, issue. In a previous study of map learning, Thorndyke and Stasz (1980) found that successful learners differed from poor learners in the procedures they used when studying a map. In particular, effective learners frequently used procedures that required the encoding of spatial configurations of

map information, while poor learners did not. However, subjects with high visual memory ability were somewhat more likely to use such spatial learning procedures than low ability subjects. This latter result suggests that spatial ability, rather than procedure selections, may underlie the observed differences in performance. The few previous studies that have directly contrasted the predictive power of abilities and strategies for performance have utilized verbal learning paradigms. For example, studies of short term retention support the hypothesis that abilities are correlated with performance even when differences in procedure usage are controlled (Cohen & Sandberg, 1977; Lyon, 1977). However, a study of immediate recall of longer word lists favored procedures over abilities as a predictor of verbal learning performance (Frederiksen, 1969).

Most studies investigating individual differences in abilities measure differences with traditional psychometric tests. This approach is somewhat problematic, since ability tests are complex cognitive tasks themselves which differ in their complexity and in the underlying low-level processes required for performance. Thus, strictly speaking, an ability test does not measure a single underlying process. Recent work has attempted to define abilities in process terms (Carroll, 1976), but many more studies are needed before process distinctions can be made.

Although not defined in process terms, psychometrically measured abilities provide a starting point for process oriented research. Factor analyses of ability test scores highlight certain aspects of information processing (e.g., verbal or spatial processing) in which there are prominent individual differences (Carroll, 1976). Since we have some understanding of processes required for map learning (Thorndyke &

Stasz, 1980), we have some basis for selecting particular abilities to measure. Thus we can select tests that require a subset of the processes required in the map learning tasks. The rationale for selecting specific abilities will be further addressed in this paper.

Recognizing the limits of process interpretations of ability test scores, the goal of the present research was to investigate the relationships among abilities, procedures, and performance on a map learning task. We collected data on subjects' spatial and verbal abilities and observed their learning procedures to determine which was most predictive of learning rate. By obtaining both spatial and verbal ability scores for subjects we could also examine whether subjects' abilities influenced their choice of particular procedures. Since the results of our earlier study guided our selection of abilities to measure, we shall briefly review that experiment.

Effective Map Learning Procedures

To identify the procedures that subjects used to learn a map, Thorndyke and Stasz (1980) analyzed verbal protocols of subjects attempting to memorize two maps (shown in Figures 1 and 2). By contrasting the protocols of good and poor learners, we identified six effective learning procedures: partitioning, imagery, memory-directed sampling, pattern encoding, relation encoding, and evaluation.

Partitioning is a procedure for focusing attention on a subset of the map information. Learners partition the map in two ways: by subdividing it spatially into smaller areas or by defining conceptual categories on which to focus (such as roads). Imagery involves the construction of a visual image of some portion of the map. For example, a

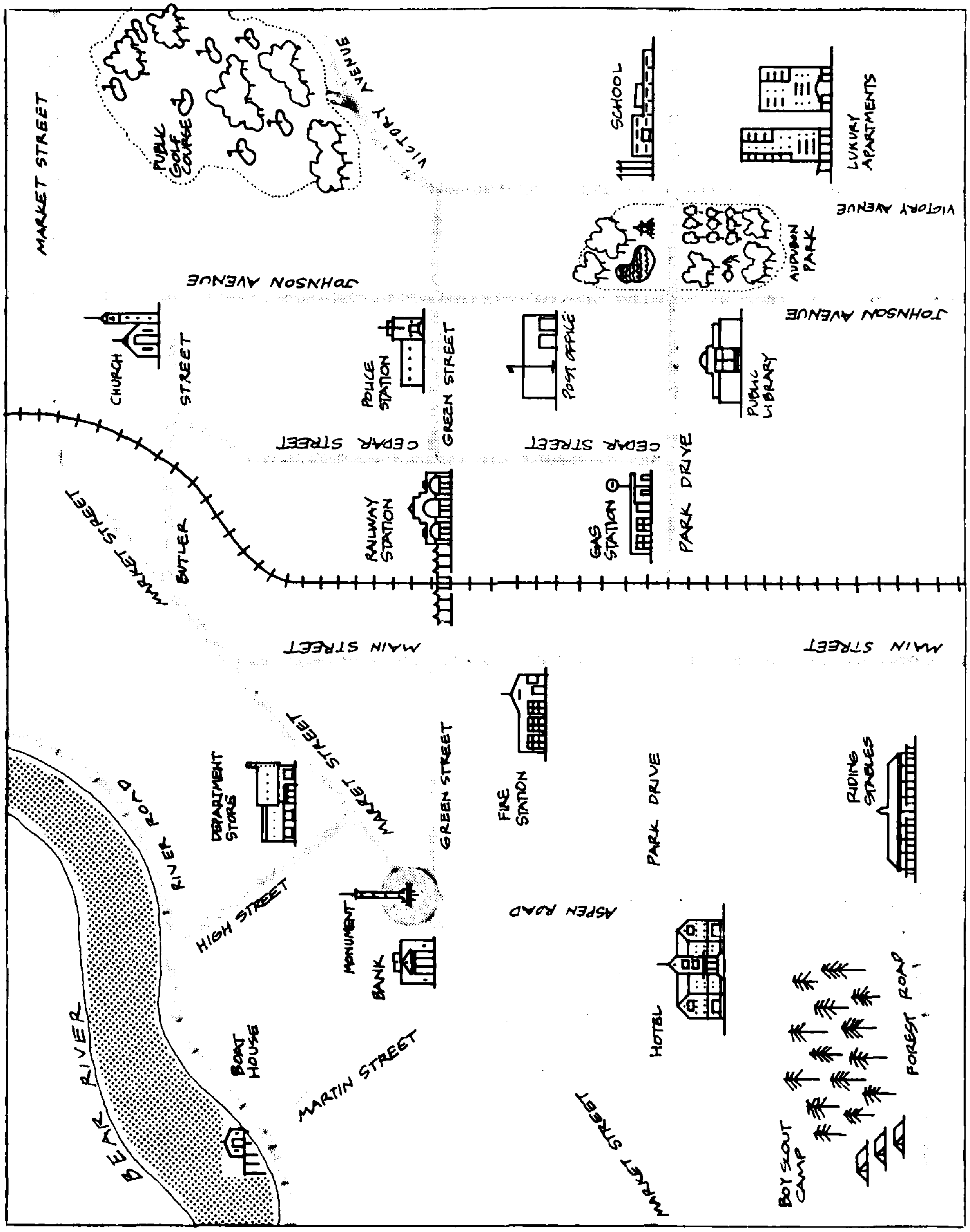

Fig. 1--The Town Map

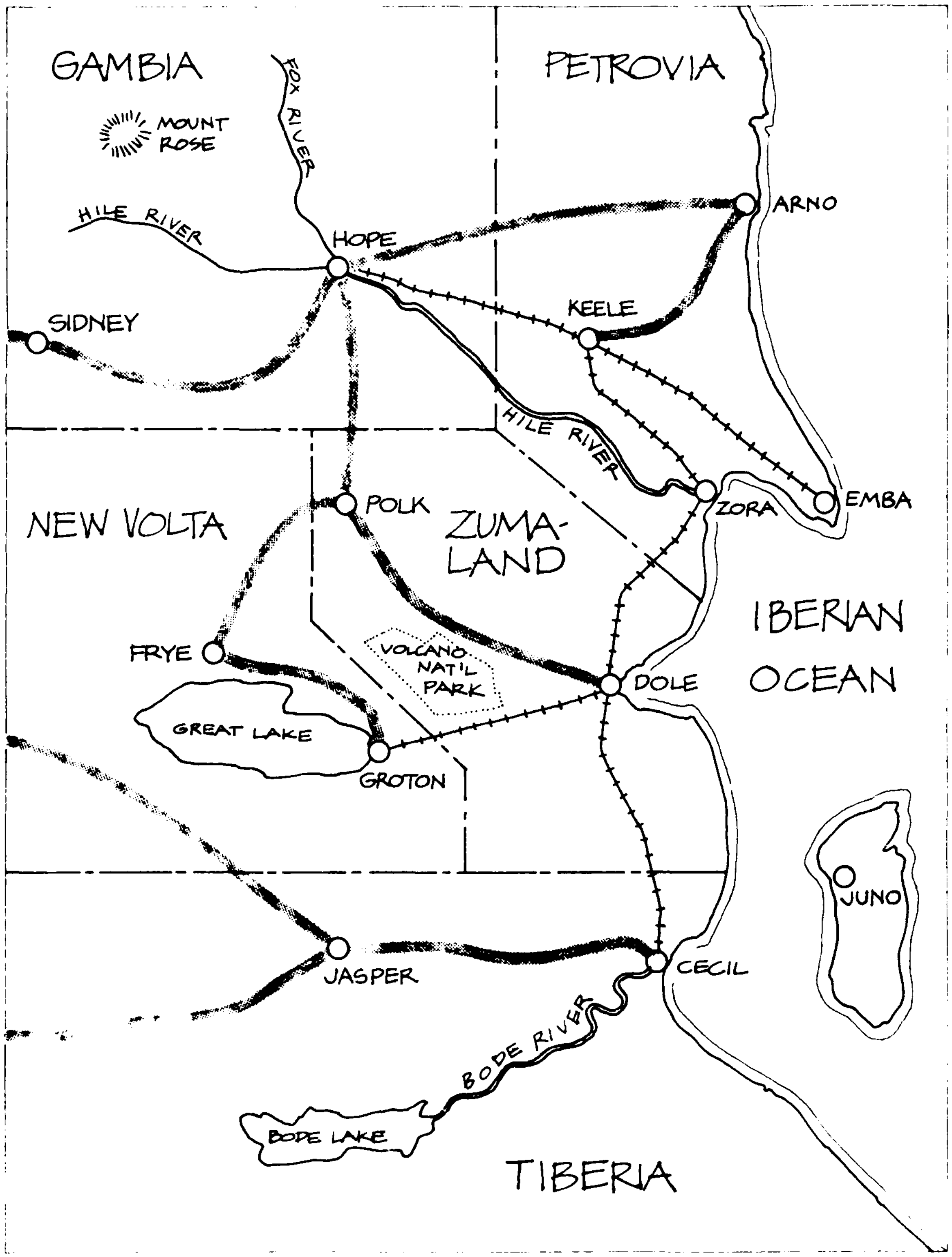

Fig. 2--The Countries Map

subject might encode a mental image of the country boundaries in Figure 1. Memory-directed sampling requires the maintenance in memory of a list of elements that a subject cannot recall correctly when attempting to draw the map. On the next study trial the subject searches for and studies those elements immediately. Pattern encoding entails the isolation and encoding of particular spatial features of a single map element. For example, a subject might notice that the northern section of Cedar Street curves to the right (see Figure 1). Subjects employed the relation encoding procedure to learn spatial relationships between two or more map elements. A subject might note, for example, that the monument in Figure 1 is located at the junction of Green Street and Aspen Road. Subjects invoked the evaluation procedure to monitor their learning progress by deciding which elements they had already learned and which they needed to study.

Good and poor learners differed primarily in the frequency of using these six procedures. Good learners structured the learning task by segmenting the maps into several information clusters and systematically learning each cluster (the partitioning procedure and memory-directed sampling). They used primarily spatial encoding procedures (imagery, pattern encoding, relation encoding), while poor subjects relied more heavily on verbal learning procedures. Finally, good learners evaluated their progress continually and accurately, using the results of those self-evaluations to guide their study behaviors (evaluation, memory-directed sampling). In contrast, poor learners used these procedures less frequently and were less accurate in their judgements about their acquired knowledge.

These differences in the processes by which subjects studied the map influenced learning progress in obvious ways. Since poorer subjects made fewer decisions about how to partition and sample map information, they were overwhelmed by the amount of information to learn and/or they studied it haphazardly. Their failure to adopt procedures most appropriate for learning spatial information resulted in relatively poor recall of the spatial attributes of the maps. Furthermore, poor learners' inaccurate evaluations led to misguided study behaviors.

It is possible that differences in subjects' abilities might underlie these differences in subjects' learning success and learning procedures. Such ability differences might influence performance in two ways. First, the use of particular procedures may depend on abilities. For example, Thorndyke and Stasz's (1980) best map learner reported that he had good visual memory and frequently used imagery to learn and remember information. In contrast, the worst learner reported that he had never experienced having mental images. He used primarily procedures for learning the names of map elements and did not attempt to learn the more complex spatial configurations on the map. Thus, these subjects' procedures matched their self-reported abilities. In a second experiment, subjects' tendency to use spatial learning procedures taught to them during a training session depended on their psychometrically assessed visual memory ability. Thus, subjects' ability may, to some extent, influence the learning procedures they adopt.

A second way in which ability differences might influence performance is in determining the success of each application of a study procedure. For example, we observed that while all learners used the evaluation procedure, poorer learners were less accurate in their

evaluations. Evaluation requires subjects to retrieve knowledge from memory and compare it to the same information on the map. In carrying out this process, subjects might create a visual image of the stored knowledge for comparison with the actual map. This representation may be more clear, detailed, or accurate for subjects with better visualization ability.

Thus, both the choice and success of learning procedures might depend on more fundamental processing abilities. We designed the present study to directly investigate these potential ability-procedure interactions.

Selection of Ability Measures

We identified two abilities that seemed particularly related to the task of map learning: field-independence and visual memory. Field-independence (FI) and field-dependence (FD) are cognitive style constructs that refer to particular habitual patterns or preferred strategies of information processing (Cronbach & Snow, 1977). FI is measured by perceptual tests in which the subject must overcome some visual or postural context to solve a problem. In the embedded figures test, for example, subjects must locate a simple figure within a complex design. Individuals who easily locate the simple figures are said to be field independent, while those who have difficulty with the task are field dependent.

Theoretically, differences in task performance derive from cognitive restructuring ability. Restructuring requires the subject to perceive objects as distinct from their context, to reorganize or segment a field, or to provide organization to a field which has little inherent

structure of its own (Witkin & Goodenough, 1977). FI individuals can readily perform such restructuring, while FD individuals are more constrained by the prevailing organization of a stimulus array.

A vast body of literature accumulated over the past 25 years has documented the FI-FD cognitive style as an influential contributor to performance in a wide range of activities (e.g., Witkin, Moore, Goodenough, & Cox, 1977; Witkin, Dyk, Faterson, Goodenough, & Karp, 1962,1974). Specifically, FI individuals can achieve alternative viewpoints in perspectivism tasks, show conservation on Piagetian transformation tasks, break perceptual sets in Einstelling problems, and provide organization for an incomplete figure in speed-of-closure tasks (Witkin, Goodenough, & Oltman, 1977). Restructuring ability also influences an individual's general approach to problem-solving and concept attainment tasks (Goodenough, 1976) and adoption of specific learning strategies on memory tasks (e.g., Meshoren, 1970). FI individuals tend to actively and consciously select strategies and test hypotheses in performing such tasks. In contrast, FD individuals assume a more passive role in such problem situations and exhibit a less structured approach to learning or problem-solving.

These differences between FI and FD individuals may have implications for map learning. Two aspects of the learning task might contribute to performance differences between FI and FD individuals: the visual complexity of the stimulus and the unstructured learning situation. Since FI individuals excel in tasks that require structuring a visual field, they may adopt learning procedures that organize the information on the map into subsets that can be learned in succession. This technique would reduce the learning task to a set of less complex,

more manageable subtasks. This would require not only the formulation of a learning plan but the ability to segment and reorganize the visual stimulus. Thus, these subjects might be expected to make extensive use of the partitioning procedure and procedures for systematically selecting elements of the map on which to focus. In contrast, the relative inability of FD individuals to perform visual-spatial restructuring suggests that these subjects may be simply overwhelmed by the visual complexity of the stimulus and may study the map haphazardly.

The second ability variable we selected for study was visual memory ability--that is, the ability to remember the configuration, location, and orientation of purely spatial or pictorial information. The large amount of spatial information on maps prompted the inclusion of this ability. Performance on the visual memory tests requires the formation of a visual representation, which is also a requisite for map learning. Thus, we expected that subjects with better visual memory would learn more spatial information from the map than low ability subjects. We also expected that high ability subjects would make more extensive use of spatial learning procedures, particularly visual imagery.

While we expected both of these abilities to influence performance, we did not assume that the two abilities were unrelated to each other. Although a conclusive relationship between visual memory and FI has not been established, there is some evidence that FI individuals have better visual memory than FD individuals (Snow, Marshalek, & Lohman, 1976; Witkin, 1973).

In order to isolate any potential influence of FI and visual memory differences abilities from other obvious individual differences, we attempted to control for subject differences in general intelligence and

memory. Accordingly, we also selected verbal comprehension and reasoning tests as indicators of general intelligence and several tests of verbal associative memory as indicators of verbal memory ability.

II. METHOD

Subjects

Ninety-four UCLA undergraduates participated in order to satisfy a course requirement. Each subject performed a battery of ability tests in an initial screening procedure. The battery comprised seven tests: a measure of field-independence (the Group Embedded Figures Test (GEFT), Oltman, Raskin, and Witkin (1971)); two measures of visual memory (the Building Memory (BLDG) and Map Memory (MAP) tests); a measure of verbal comprehension, (the Extended Range Vocabulary Test (VOC)); a measure of general reasoning (the Necessary Arithmetic Operations Test (MATH)); two measures of associative memory (First and Last Names Test (NAME) and a twenty-item free recall test (FR)). Except for GEFT and FR, the tests were chosen from the *Kit of Factor Referenced Cognitive Tests* (Ekstrom, French, & Harmon, 1976).

Ability test scores were used to select subjects for the map-learning experiment. Since FI was the variable of primary interest, first selection was made on the basis of GEFT scores. We selected individuals who fell into one of two extreme groups: a group of relatively FI and a group of relatively FD subjects. We equated the subjects in the extreme groups on general ability (measured by VOC and MATH) and memory ability (measured by NAME and FR) by including only individuals within one standard deviation from the overall mean on each of these tests. Visual memory ability remained a continuous variable within each extreme group. Thus constructed, the sample comprised thirteen FD subjects (six males, seven females) and twelve FI subjects (seven females, five males). Each received $3.50 per hour for the subsequent experiment.

Ability Tests

A brief description of each ability test follows. The GEFT required subjects to select from a set of simple geometric figures the one that was embedded in a more complex design. The BLDG test required subjects to indicate the location of a number of buildings seen on a previously studied map. On the MAP test, subjects attempted to recognize a set of briefly studied maps in a set of similar distractors. The VOC test measured vocabulary knowledge by requiring subjects to identify word synonyms. The MATH test measured the ability to select and organize relevant numerical operations for the solution of algebraic problems. In the NAME test, subjects studied full names and were then required to recall the corresponding first name for each of the presented surnames. In the FR test, subjects heard and then attempted to recall a list of twenty high-frequency, unrelated nouns. The procedure was repeated with a new randomization of the words on the list over four trials.

Map Materials

The maps shown in Figures 1 and 2 served as learning materials. The Town Map (Figure 1) contained 33 elements or conceptual entities typically found in a small town (e.g., streets, parks, buildings). With the exception of the railroad track, all of the map elements had names associated with them. The Countries Map (Figure 2) differed from the Town Map in scale, content, and number of named elements. Roads and railroads did not have names, but all other elements were labeled.

Procedure

After the initial screening sessions, the 25 selected subjects returned individually on another day to perform an additional ability test followed by the map learning task. The ability test, the Portable Rod-and-Frame Test, (PRFT; Oltman, 1968), provided a second measure of FI. This test measures the extent to which perception of an object is determined by a surrounding, distracting framework. The subject views a rod within a frame when both are tilted at various angles. The subject must indicate when the rod is vertical, regardless of the position of the surrounding frame.

Following this test, the subject was instructed that he or she would now be presented with a map to learn over a series of six study-recall trials. The subjects' task was to learn the map well enough to be able to draw it and answer questions about its contents. During study trials the subject was required to "think aloud" about what he or she was looking at and what his or her techniques were for attending to and learning the information. A practice trial on a different map familiarized the subject with the study-recall and thinking-aloud procedures. The experimenter then gave the subject a copy of either the Town Map or the Countries Map to study for two minutes. During that time, the experimenter tape recorded the subject's verbal protocol. After two minutes, the experimenter withdrew the map and instructed the subject to draw on a clean sheet of paper as much of the map as he or she could remember. Drawing time was not limited. Six study-recall trials (or fewer if the subject had learned the map perfectly) were provided. Following the last trial, the subject solved eight route-finding and spatial-judgment problems from memory. To solve these problems the

subject was required to recall and integrate route and location information from the map. For example, one problem from the Countries Map required subjects to name the cities they would pass through if they traveled from Groton to Hope by train. Solutions to these problems were tape recorded. Following a 10-minute break, this procedure was repeated with the second map. Order of map presentation was counterbalanced across subjects. Testing time varied across subjects from two and one-half to three hours.

III. RESULTS

To score subjects' maps, we treated each element as having potentially two attributes: a spatial location and a verbal label. (One element on the Town Map and 16 on the Countries Map had no verbal label.) We scored recall of spatial and verbal information separately using the decision rules described in Thorndyke and Stasz (1980). For each subject, we computed three scores on each learning trial: proportion of verbal attributes recalled, proportion of spatial attributes recalled, and proportion of entire elements recalled (all attributes correct).

We interpreted subjects' performance on the eight problems as a test of the reliability of the recall data. If the recall data were reliable, then these data should predict subjects' problem-solving performance, since the retrieval of map knowledge was required for problem-solving. As expected, subjects' problem-solving performance was highly correlated with last trial recall: $r = .74$, $p < .001$ for the Town Map; $r = .62$, $p < .001$ for the Countries Map.

We scored subjects' verbal protocols to determine the set of study procedures each used to learn the maps. These analysis procedures were the same as those previously used and described in detail (Thorndyke and Stasz, 1980). The Appendix to the present paper lists the complete set of identified procedures, their operationalizations, and examples of each. This scoring procedure yielded, for each subject, the frequency of occurrence of each procedure on each of the study trials.

To determine the consistency of performance across the two maps, we computed correlations between subjects' mean recall across the six

trials on one map with recall on the other map. These correlations indicated that performance was highly reliable, $\underline{r} = .66$, $\underline{p} < .001$ for spatial attributes; $\underline{r} = .45$, $\underline{p} < .01$ for verbal attributes. Similarly we correlated the mean occurrence of each procedure across trials for the two maps. The number of occurrences of a procedure on one map significantly correlated with the number of occurrences of the same procedure on the other map for 14 of the 17 procedures. Thus, subjects' study techniques were similar for both maps. As a result, we combined both the recall and procedure scores across the maps for each subject for use in all subsequent analyses.

Procedure Use and Performance

The first analysis focused on procedures use and map learning. To determine the characteristics of successful map learners, we contrasted the procedure profiles of good learners with those of poor learners. We defined good learners as subjects whose last trial recall, averaged across the two maps, was at least 90 percent. This criterion distinguished 12 good subjects from 12 poor subjects. (We could not unambiguously classify one subject who had high recall on one map but scored below average on the other). Table 1 shows the mean recall scores and procedure usage frequencies for the two groups. The last two columns of Table 1 give the means and standard deviations across all subjects for each variable. Mann-Whitney U-Tests were used to evaluate the significance of the obtained differences.

Good learners recalled more of both the spatial and verbal attributes than the poor learners as shown in rows 2 and 3 of Table 1. In addition, good learners used four procedures significantly more frequently than

Table 1

MEAN RECALL AND PROCEDURE USAGE FOR
GOOD AND POOR LEARNERS

Variable	Good Learners	Poor Learners	Mean	SD
Percent complete elements	65.2 *	46.6 *	56.0	12.1
Percent spatial attributes	69.3 *	50.2 *	59.8	12.3
Percent verbal attributes	76.8 *	71.1 *	74.2	6.4
Partitioning	3.2	1.5	2.5	2.3
Random sampling	.0	.8	.4	1.1
Stochastic sampling	4.2	4.4	4.4	1.6
Systematic sampling	2.3	1.7	1.9	1.7
Memory-directed sampling	6.2	3.8	5.3	3.4
Element naming	25.7	30.9	28.9	17.2
Rehearsal	59.0	64.3	60.9	50.8
Association	7.2	5.6	6.3	7.5
Mnemonics	1.6	1.6	1.5	2.5
Counting	4.7	3.2	4.1	4.3
Imagery	5.0 *	3.0 *	3.8	2.9
Spatial labeling	4.3	5.0	4.6	3.8
Pattern encoding	14.3 *	10.2 *	12.4	5.8
Relation encoding	77.2	68.4	71.9	28.4
Planning	1.9 *	.2 *	1.0	2.1
Evaluation	18.2 *	7.9 *	13.7	11.9
Percent correct evaluations	98.2 *	88.0 *	93.1	13.6

* $p < .05$

poor learners. Three of these belong to the set of effective procedures we have previously identified (Thorndyke and Stasz, 1980) and discussed above: imagery, pattern encoding, and evaluation. In addition to using the evaluation procedure more frequently, good learners were more accurate in their evaluations, as the last row of Table 1 shows. Accuracy of evaluations also distinguished good from poor learners in our previous research. Good learners also used the other three previously identified effective procedures (Memory-Directed Sampling, Partitioning, and Relation Encoding) more frequently than poor learners. However, these differences were not statistically reliable.

Good and poor learners also differed in their overall approach to the learning task. Some good learners adopted a planning strategy at the outset of the learning task. These subjects would develop a plan for learning the map that would suggest a particular set and sequence of procedures. For example, one subject stated on Trial 1 that he would first study and learn the spatial configurations of information, and then on later trials attempt to learn the names of the elements. As Table 1 shows, good learners used a planning strategy more frequently than poor learners. A more detailed analysis of these strategies is provided elsewhere (Stasz, 1979).

In sum, the present findings corroborate our earlier research in map learning. Good learners formulate and execute a learning plan. They employ effective strategies to learn spatial attributes of the map. Finally, they evaluate their learning performance consistently and accurately, and use evaluative feedback to guide their study behavior. By contrast, poorer learners employ these effective procedures less frequently and adopt a more haphazard approach to learning.

Ability and Performance

To determine the relationships among the various abilities tests, we performed correlations among the ability scores. Table 2 presents these correlations. Performance on the two visual memory tests (MAP and BLDG) was reliably correlated. Further, both of these tests correlated with field independence, as measured by the Embedded Figures Test (GEFT).[1]

---

[1] The relationship among tests of FI, vocabulary, and spatial

Table 2

CORRELATIONS AMONG ABILITY TESTS

Test	1	2	3	4	5	6	7
1. GEFT							
2. PRFT	-35						
3. BLDG	63	-01					
4. MAP	51	-05	45				
5. VOC	31	-48	-03	25			
6. MATH	11	24	55	30	01		
7. NAME	16	23	61	32	-14	22	
8. FR	35	07	58	46	-04	16	61

NOTE: *r* of .41 is significant at .05 level, two-tailed

abilities found here highlight the controversy about the role of FI in broader psychometric theories of intelligence. While marker tests of FI (GEFT, PRFT) are typically correlated, it is frequently postulated that they really measure somewhat distinct abilities (Horn, 1976; Witkin & Goodenough, 1977). Since close associations between disembedding tests, such as GEFT, and spatial tests have been previously noted (Snow, Marshalek, & Lohman, 1976; Witkin, 1973), GEFT may represent a primary visualization ability. PRFT-type tasks, however, may involve a visuo-kinisthetic function that is largely independent of G and other primary ability factors (e.g., visualization). The correlations presented in Table 2 support this interpretation. GEFT correlates more highly with tests of visual memory (BLDG, MAP) than with PRFT or vocabulary. On the other hand, PRFT and VOC correlate significantly with each other but not with other tests. The most parsimonious interpretation is thus to identify GEFT with spatial-visualization ability.

In order to examine the influence of ability on task performance and procedural usage, we contrasted performance between selected ability groups. Since GEFT scores were significantly correlated with BLDG scores (r = .66), it seemed reasonable to combine these data to form two extreme ability groups. Therefore, we performed a median split within each extreme FI group on the basis of BLDG scores. This process resulted in the formation of four groups of the following sizes: field independent, high visual memory subjects (FI-HI), N = 10; field independent, low visual memory (FI-LO), N = 2; field dependent, high visual memory (FD-HI), N = 3; field dependent, low visual memory (FD-LO), N = 10. Since we were most interested in the contrast between extreme ability groups, further analyses were conducted on subjects in the FI-HI and FD-LO groups only.

Table 3 shows mean recall performance and number of occurrences of each study procedure for two groups. To determine if these performance and procedure differences were significant, we computed Mann-Whitney U-tests (N = 10. alpha level = .05). FI-HI subjects had higher recall of complete elements and spatial attributes than did FD-LO subjects. However, the groups did not differ significantly on recall of verbal information from the maps. This finding was expected, since studies of verbal learning in associative, free recall, and recognition paradigms have found no systematic differences between FI and FD individuals (Goodenough, 1976).

FI-HIs used the following procedures more frequently: partitioning, stochastic sampling, systematic sampling, memory-directed sampling, counting, imagery, pattern encoding, relation encoding, evaluation, and the planning strategy. This set includes all but one of the spatial

Table 3

MEAN RECALL PROPORTIONS AND FREQUENCIES
OF PROCEDURE USE FOR ABILITY GROUPS

Variable	FI-HI	FD-LO	
Percent complete elements	62.2	50.2	*
Percent spatial attributes	66.5	54.0	*
Percent verbal attributes	76.5	70.7	
Partitioning	2.7	2.0	
Random sampling	.2	.6	
Stochastic sampling	4.4	4.0	
Systematic sampling	2.1	2.0	
Memory-directed sampling	5.7	4.5	
Named elements	25.3	34.4	
Rehearsal	54.6	80.8	
Association	4.7	9.3	
Mnemonics	.9	2.1	
Counting	5.4	2.9	
Imagery	5.4	3.0	*
Spatial labeling	2.9	5.7	
Pattern encoding	13.3	9.5	
Relation encoding	80.6	65.7	
Planning	1.8	.7	
Evaluation	15.9	12.0	

* $p < .05$

learning procedures and all of the procedures identified as most predictive of map learning in the present and previous studies (Thorndyke & Stasz, 1980). Among these, only the difference for the imagery procedure was significant. By contrast, FD-LOs made more frequent use of random sampling and primarily verbal learning procedures (named elements, association, mnemonics). Although few differences in procedures use were statistically significant, there is a tendency for high ability subjects to use the previously identified effective learning procedures. These results seem to indicate that performance differences between

ability groups stem from both differences in procedure selections and from differences in the success with which procedures are used. Evidence for the latter possibility was found by Thorndyke and Stasz (1980). When controlling for differences in procedure use, they found that high quality subjects still performed better.

To determine whether recall differences between these groups could be attributed specifically to visual-spatial ability, we compared mean ability test scores of the extreme FI-HI and FD-LO groups. Since BLDG was correlated with several other ability tests (see Table 2), we expected the groups would differ on some of these tests. Mann-Whitney U-Tests, with sample sizes of 10 and an alpha level of .05, were used for these comparisons. Reliable group differences were found for MATH, MAP, NAME, and FR. Since the groups were intentionally constructed to differ in spatial abilities, we are not concerned with test differences associated with that ability (MAP). The MATH score is also of little concern, since general reasoning is not an important component of this task. A high correlation between FI and mathematics skills has been previously noted (e.g., Witkin et al., 1977), and is more likely to be found with this extreme group design. Finally, since the groups did not differ in verbal recall, differences in associative memory (NAME, FR) are important only if they significantly affected total and spatial recall. To answer this question, we computed correlations between the ability test scores and recall for the subjects. Associative memory did not correlate reliably with recall: $r(FR) = .18, .18$; $r(NAME) = .29, .19$, for total complete element recall and spatial recall, respectively. It thus seems reasonable to conclude that observed group differences may be attributed to differences in specific visual-spatial abilities, not general memory ability.

Predictors of Map Learning

These analyses indicate that good and poor learners differed both in the learning procedures they used (see Table 1) and in their visual-spatial abilities (see Table 3). We thus performed multiple regression analyses to determine the relative importance of abilities and procedures in predicting map learning performance. Separate regressions were carried out for complete element recall, spatial recall, and verbal recall. For each regression analysis we selected the subset of ability tests and procedures with simple correlations with an absolute value of at least .20 with the dependent variable. In addition, we included those procedures that had predicted map learning in our earlier studies. No regression included more than ten independent variables to predict the 25 observations of the dependent variable. Regressions for complete element recall and spatial recall included the following independent variables: pattern encoding, imagery, evaluation accuracy, evaluation, memory-directed sampling, partitioning, relation encoding, BLDG, GEFT and MATH. The regression for verbal attribute recall contained the following independent variables: evaluation, stochastic sampling, imagery, memory-directed sampling, random sampling, NAME, FR, and BLDG.

Following Carroll (1978), for each dependent variable we performed successive multiple regressions using a backward elimination technique. This technique successively reduces the number of predictor variables by eliminating at each step the variable contributing the least to the prediction equation. The elimination procedure continues until the equation contains only those variables that are significant predictors. The results of these analyses are shown in Table 4.

Table 4

VARIABLES REMAINING IN REGRESSION EQUATION

Regression	Variable	R^a	R^2 Increment[b]	R Full Model[c]
Complete Element Recall	BLDG	.62	.39	.80
Spatial Attribute Recall	BLDG	.61	.37	.825
Verbal Attribute Recall	NAME	.64	.41	.825
	Evaluation	.71	.10	

[a] Multiple correlation coefficient

[b] Proportion of variance accounted for by each variable

[c] Multiple correlation for regression model containing all variables

For complete element recall, the entire set of independent variables accounted for 64 percent of the variation in performance. Only one variable, the BLDG test, contributed significantly to subject variation. It is thus the single best predictor of performance on the map learning task. The other variables that were highly correlated with learning performance were also significantly correlated with BLDG. These included pattern encoding, evaluation, memory-directed sampling, GEFT, and MATH. This necessarily reduced their potential contribution as distinct predictors of subject variation.

The regression of spatial attribute recall on the same abilities and procedures produced similar results. All variables accounted for 68 percent of subject variation, and BLDG was the sole significant best

contributor to prediction of recall variation. The high correlation between BLDG test performance and spatial recall is not surprising in light of the similarity between the memory demands of the two tasks.

For verbal attribute recall, the independent variables accounted for 68 percent of the variation. Two variables contributed significantly to verbal recall: NAME test performance and the evaluation procedure. This finding indicates that subjects with high verbal associative memory do particularly well learning verbal attributes. In addition, more frequent use of the evaluation procedure predicts recall of verbal attributes.

IV. DISCUSSION

This study assessed the effects of differences in ability and learning procedures on knowledge acquisition from maps. Psychometric tests of visual-spatial ability were highly correlated with recall of spatial attributes of the map and with overall learning performance, while associative memory ability was most correlated with verbal attribute recall. Subject-selected procedures for encoding spatial information and assessing learning progress also distinguished the behaviors of successful and less successful learners. These same procedures accounted for much of the variation in map learning performance in our previous research (Thorndyke & Stasz, 1980). Although both ability differences and procedure use were important contributors to performance, a direct comparison of these sources of variation suggested that abilities are most predictive of map learning. This result may, to some extent, be explained by the fact that the ability tests most predictive of map learning performance (BLDG, NAME) were similar to the map learning task itself. Furthermore, other analyses made it clear that abilities were not the sole determinants of performance. A direct comparison of good and poor learners revealed several significant differences in procedure usage. At the same time, subjects of high and low ability differed little in the study procedures they chose. These observations lead us to the following conclusions: (1) the use of effective study procedures can influence map learning performance, and (2) high ability subjects benefit more from the use of these procedures than low ability subjects.

These conclusions raise the interesting question of whether or not the performance of low ability subjects can be improved through training in the use of study procedures. In the traditional psychometric view, abilities and performance on tasks relying heavily on those abilities are relatively resistant to change. Indeed, in our earlier map learning study (Thorndyke and Stasz, 1980) we found that low visual memory ability subjects showed little improvement in learning rate after being trained to use effective study procedures. In contrast, medium and high ability subjects show significant improvements as a result of this training. This result is consistent with the psychometric position. However, two conditions of that experiment qualify the strength of the evidence in support of the stability of low ability subjects' performance. First, subjects in that study received training in the use of six procedures in a training session lasting fewer than 30 minutes. Thus the extent of instruction and subjects' practice was minimal. More extensive training may alter the effectiveness of these procedures. Second, half of the trained procedures required the encoding and manipulation of spatial information. This required low ability subjects to utilize those particular skills in which they were already deficient. It is possible that another set of procedures, not requiring the use of visual memory, could significantly benefit these subjects on map-learning tasks. However, since spatial learning strategies seem important for this task and training in other strategies does not improve learning, training seems an unlikely solution. Perhaps, for these subjects, optimal instructional design may consist of manipulating the materials to convey the information in another form. Until more direct tests of training are conducted, we consider the modifiability of low ability subjects' performance an open question.

Appendix

LEARNING PROCEDURES OBSERVED IN THE PROTOCOLS

PROCEDURES	DEFINITION	EXAMPLES
ATTENTIONAL PROCEDURES	Procedures required for perception of the physical map	
1. Partitioning	Focusing attention: Subjects restrict eye fixations to a particular subset of map information	
a) by spatial region	Subject defines specific area or location on map	-area above Market St. -area in the south-west corner
b) conceptual category	Subject defines conceptual class of elements in a cluster or chooses specified class of elements	-streets -buildings -country borders -railroads -cities on the coast
2. Sampling:	Switching attention: Subjects shift their current focus of attention to a new location	
a) random	Subject focuses attention haphazardly around the map, with the new focus independent of previous focus in both location and content	-studies building location on Market St. then moves to riding stables
b) stochastic	Subject does not define a starting point, but shifts focus from current element to an adjacent element in no systematic or consistent direction	-studies apartments, moves to school, park, library, Victory Ave., etc.
c) systematic	Subject shifts focus according to a subject-defined decision rule or criterion	-S begins at Bear River, studies contiguous elements from left-right across map -learns vertical sts. from Market, a distinctive diagonal -studies main geographical features -studies large objects

d) memory directed	Can occur on any trial after the first, when subject decides to study particular elements that had not yet been learned	-I'm looking at these streets that gave me trouble last time -I got the park on the wrong side of Johnson It's between Johnson and Victory
ENCODING PROCEDURES	Procedures to maintain information in working memory, encode and elaborate it in long-term memory and integrate it with other learned information	
3. Rehearsal	Subject verbalizes names of elements in lists, repeats element name, element relaships, etc. within the same trial	-Zora, Emba, Keele, Zora, Emba, Keele..
4. Element naming	Subject says aloud the name associated with a particular map element	
5. Association	Subject elaborates verbal attributes by association to or embellishment with some related prior knowledge in three ways: i) supply a category name that subsumed a set of elements ii) suggest a semantic relationship between several elements iii) supply an action or narrative	-reminds me of the library and park I go to in Washington -bank, department store--a commercial district -Forest Rd. in the forest by the Boy Scout Camp...that makes sense
6. Mnemonics	Subject generates memorable retrieval cue for set of names by using the first letters of their names or noting that the first letters of elements were in alphabetical order	- VJMA = Victory, Johnson, Market, Aspen - SHAK = Sidney, Hope, Arno, Keele
7. Counting	Subject enumerates the elements sharing a particular property	- There are 5 political subdivisions - four vertical streets from Market - five cities on the coast

8. Visual imagery	Subject closes eyes and tries to image map while naming elements; subject reports that he compares map with mental picture	
9. Labeling	Subject generates verbal cue for recall of a complex spatial configuration	- coastline looks like a profile - roads form the torso of a man - the triangles make a bow-tie
10. Pattern encoding	Subject notices particular shape or pattern of a single element, not in relation to other elements	- Victory curves around there - Market goes up and across
11. Relation encoding	Subject notices spatial relationships between 2 or more elements. Fifteen relational predicates of two arguments and two predicates of three arguments were identified. Arguments could be either element names, a location defined by the intersection of two roads or railroads or the entire map itself. Predicates of two arguments: in, at, on, above, below, near, next to, intersects, middle, center of, parallels, north, east, south, west Predicates of three arguments: between, connects	- Cedar, Market, and the railroad all curve there - Green goes from the monument to Main and from Cedar to Victory - monument is at the intersection of Aspen and Green - Mt. Rose is between the fork of the Fox and Hile Rivers - the railroad tracks cut it in half - Market Street is on the perimeter of town
EVALUATION PROCEDURE	Subject monitors learning process by considering which elements were already learned and which were needed to be studied	
12. Evaluation	Subject makes statement of the form--I know/don't know (element name); I think I got (element name) correct/incorrect	- I got the cities on the coast right. - I keep forgetting the name of this street
PLANNING STRATEGY	Subject states general high-level strategy on plan on action for approaching task	- I'm going to separate this map into 4 sections, then learn each one

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